Enhancing Traditional Classroom Instruction with Web-based Statics Course

Anna Dollár[1], Paul S. Steif [2], Ross Strader[3]

Abstract – **A web-based Statics course is being developed by the authors as part of the Open Learning Initiative (OLI) at Carnegie Mellon University. OLI seeks to create and sustain freely available, cognitively informed learning tools designed to provide a substantial amount of instruction through the digital learning environment. This paper highlights the potential opportunities of online learning materials to enhance a traditional lecture-based course. We also identify the challenges that online materials face in promoting learning in an engineering course in which problem solving is intimately tied with drawing, and with writing and solving equations. Examples that illustrate the potential benefits of online materials, and that address the challenges associated with learning engineering courses, are presented. Finally, user studies and initial experience in blending these materials into an ongoing Statics course are summarized.**

Index Terms – interactive learning, online learning, Statics

INTRODUCTION

In satisfying an increasing demand for technical education, as well as demands for improvements in its effectiveness, the capabilities of computers and the web need to be fully harnessed. While these new capabilities may have affected learning in some subjects, many subjects remain as they have been traditionally taught, with lecture and textbook homework problems. We have also witnessed rapid increases in the understanding of how people learn [1]. It is time to couple this evolving understanding with improvements in computer technology, to fundamentally rethink the learning process in many subjects.

The online Statics course, which was presented as a work-in-progress at FIE [2], is being developed by the authors and is available at the OLI website, http://www.cmu.edu/oli/ (to access the course click on the Statics logo, and on the following page click on "Open & Free Version"). Completion of the course is scheduled for summer 2008.The course draws upon the authors' previous work [3, 4] to reorganize Statics instruction to better address the conceptual challenges students face. The course is divided into approximately twenty modules, each based on carefully articulated learning objectives. Each module contains some expository text and a large variety of exercises and simulations, which capitalize on the computer's capability to promote interaction and to display digital images and video. Student learning is supported through frequently interspersed "Learn by Doing" activities, which offer hints and feedback. Summative "Did I Get This" interactive assessments signal to students whether objectives are met and offer scaffolding when appropriate.

While these materials can support learning effectively under multiple scenarios, such as by completely independent learners, or by asynchronous and distance learners in an online course with a lead instructor, here we describe their use in a so-called blended mode: in a traditional lecture class with an instructor. When deficiencies in the time honored approach are acknowledged, we can identify particularly fruitful opportunities for computer-based materials. For example, lecture is sometimes inconvenient: the words and drawings of the instructor come only once, not necessarily when the student is most prepared to assimilate them. Traditionally, the opportunities for displaying phenomena dynamically were minimal. While computers and projection systems in the classroom do allow instructors to show such phenomena (should they take advantage of them), they are run according to the instructor's whim, not the learner's. The principal activity outside of class is solving homework problems. Here, feedback during practice would be most beneficial, but the feedback loop is particularly weak: students typically get "graded" homework back, say, one week later, possibly even after they have completed the subsequent assignment and too late to be useful. Rather than waiting until exams to recognize their deficiencies, students would benefit from early, if not instantaneous, assessment. In this paper, we explain how interactive online course materials can address these deficiencies, as well as the challenges of using the computer for instruction in engineering courses, and then we display examples of our learning materials.

OPPORTUNITIES FOR IMPROVED LEARNING

Active Learning

While instructors can and should promote active learning in class, this is clearly challenging to achieve in large classrooms. By contrast, computer-based materials that appropriately intersperse and sequence content, questioning, practice, and assessment can promote high levels of cognitive activity on the part of students. Students who are actively engaged in learning, learn more [5]. It is typically assumed in engineering science courses (probably correctly) that students do not read the textbook on their own; they are only engaged

[1] Anna Dollár, Miami University, dollara@muohio.edu
[2] Paul S. Steif, Carnegie Mellon University, steif@cmu.edu
[3] Ross Strader, Carnegie Mellon University, statics@strader.org

when they need to solve homework problems. However, in appropriately devised online materials, students are *actively engaged* throughout the process, with frequent, small checks on their progress, besides major problem solving episodes. Students learn through a constant iterative process of assimilating new information and testing out their evolving understanding with feedback; thus the integration of assessment into the learning process can be of great benefit [6].

Explanations combining voice and evolving graphics

Text and graphics clearly can convey content in many circumstances. But the combination of voice and graphics, which takes advantage of multiple pathways of information [7] (aural and visual), offers enormous benefits relative to textbooks, particularly when words are linked more tightly to the relevant diagrams. While an instructor can provide as good an explanation involving voice and graphics, students cannot readily ask the live instructor to *repeat selected* portions of lecture *multiple times* the way they can replay a video file. (Of course, a video file cannot respond with an altered explanation based on a student query.)

Simulations

Neither a static textbook, nor an instructor, can offer dynamic simulations of relevant phenomena, particularly simulations with parameters which are controlled by the user seeking to explore relevant phenomena or study questions that are posed. In the case of the course addressed here (Statics), simulations of motions are critical to conveying the various effects of forces, and therefore the conditions for equilibrium (lack of motion). Indeed, in other subjects, displaying the evolution of some phenomenon, possibly over time, may likely be equally beneficial, but again difficult to convey with static images.

Problem solving with individual instantaneous guidance and feedback

Tremendous benefits are associated with problem solving online as compared with the traditional practice of homework. A substantial number of textbook problems might be assigned in a traditional course, but there is relatively little effective feedback: graded homework is usually returned with minimal critique and after enough time has passed that the thought processes involved have faded. By contrast, problem solving on the computer can accommodate the user by posing a task that is directly pertinent to current learning objectives, giving the user a chance to answer independently, but then offering gradual levels of hints as appropriate, as well as informative feedback in instances of wrong answers. When attempting to solve homework problems, students sometimes need that little hint to get them going, but when it is unavailable (at 2 am), their time is wasted and frustration may be high. The individual guidance and feedback for problem solving that students can get from online material is instantaneous and right on time. Furthermore, instantaneous feedback can be used to address common student misconceptions in a manner not possible with the traditional homework format. The online activities are programmed to recognize answers corresponding to common student mistakes and to give feedback explaining the error in reasoning that results in that specific mistake.

Probe student thinking on multiple scales

Progress in learning is not only, or always best, assessed using full blown problems, such as are found in textbooks. Often, frequent short questions on fine grained issues, sometimes simply with yes or no answers, or conceptual questions that require written explanation (which can immediately be compared by the student to an expert answer), are more appropriate. In an online environment this may be more feasible than with traditional written homework. In addition, one can more easily pose conditional questions, which depend on the answers to the previous questions.

Timely assessments of progress

With the delay in returning homework, and the minimal feedback usually accompanying graded homework, students are often unaware that they are behind. Computer-based learning materials can help students recognize right away that progress is not sufficient and that additional help should be sought. In the traditional classroom they may not get the wake-up call that they have serious deficiencies until exam time. With the flexibility of the computer and the instantaneous assessment, students can more readily choose to repeat selected exercises to get more practice, as appropriate to their individual learning trajectories. In fact, we have observed students returning to materials multiple times. With such materials available, instructors might even reconsider the standard shotgun practice of assigning many problems.

Peer interaction

Online materials can form a rich basis and context for fruitful conversations between students engaged in using them in close proximity to one another (inside or outside of class). Particularly in the case of simulations, we have noticed students discussing what they were observing. We want to contrast the more typical, superficial discussion of what answer was obtained on a particular homework problem with a discussion of what is physically happening in a simulation and why.

Convenience of Review

Online materials can fruitfully be engaged multiple times, giving students opportunities to review when convenient for them, not necessarily timed with office hours. (Indeed, we have observed a decrease in the need for office hours during the periods in which the online materials were used. The materials appear to serve as both an electronic textbook and a private tutor.) Repeated engagement is feasible when there is such a large set of interactions that students would be unlikely to have merely memorized answers they saw before; they must have at least partially internalized the ideas. Future studies of the data obtained will permit deeper study of this issue.

Feedback to instructors and more productive use of class time

When online materials log student interactions, data-mining technologies can be used to track progress of, and even detailed paths taken by, individual students and the class overall. If the instructors are then allowed to interrogate these data, on both coarse- and fine-grained scales, they can zero in on those points which require further elaboration, focusing classroom instruction time more effectively. Also, there is pressure for accelerated learning: more topics are being viewed as necessary, leaving less time to focus on traditional topics. Components of the course could be assigned as "required learning" as opposed to "required reading"; then class time would be used more productively to discuss challenging subtleties, added topics of current interest, design projects, and more advanced critical thinking and problem solving activities.

CHALLENGES

Despite these potential benefits, one must not underestimate the challenges facing computer-based materials for learning engineering. A significant issue is the requirement that students, after completing the online materials, be able to solve problems on paper with drawings, symbols, and mathematics, as is traditionally done. We ultimately want them to be independent users of the subject, to transfer what they have learned to upper level courses. Clearly, we could give them written homework on the side; nevertheless, we want the online experience to contribute to the desired abilities as much as possible.

How can we ensure that the computer engages the student in as many relevant kinds of interactions as possible, interactions which increase the likelihood of transferring knowledge to circumstances when pencil and paper are to be used? Completely free form input cannot be allowed, if we expect the computer to interpret input. Nevertheless, one can take maximal advantage of clicking and typing. One can ask students to choose from several forces, to choose points where forces act, or to move a slider to an appropriate point (where a support should be). Of course, individual numbers can be entered; but with appropriate combinations of multiple drop-down menus, answers in the form of algebraic expressions with various terms and signs can be submitted. Finally, students can be asked to enter free-form explanations; although the computer can only save this input for later inspection by the instructor, the student can view an expert answer after submitting.

A second major challenge is that of good interface design – if one wants students to be fruitfully engaged without the need for external intervention, it is important to signal to users where they are and what is expected at each instant. This runs the gamut from having the operation of simulations be intuitive, to text which explains the flow (…"we will let you practice an example on your own…"), and to keeping the larger conceptual framework in the user's view.

EXAMPLES

In this section, we show examples of different elements of the online materials that seek to accomplish the potential benefits listed above.

Walkthrough

Sometimes complex explanations or lengthy procedures are difficult to follow with written text and diagrams alone. Here one can capitalize on the advantages afforded by *multiple pathways (aural and visual) to convey information*. Further, the diagrams can evolve in synchrony with the voice so the user's attention is appropriately focused. Compare this with the burdens of going back and forth between text in a textbook and the figures on the side or on the next page. When this is done with standard video controls, the user has full *ability to pause, stop, rewind, and repeat*. In Figure I we show one screenshot of a Walkthrough that explains the differences in two approaches to solving a problem.

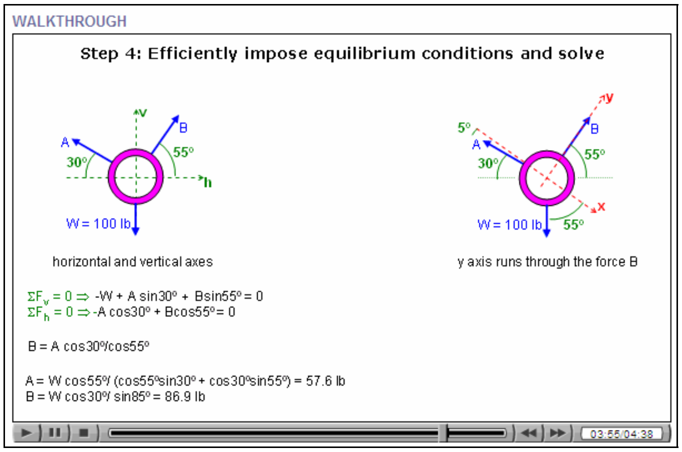

FIGURE I
WALKTHROUGH EXPLAINIG THE IMPOSITION OF EQUILIBRIUM CONDITIONS AND THE EFFECT OF DIFFERENT CHOICES OF COORDINATE AXES.

Learn By Doing

The computer can play a significant role in providing appropriate support to users who are first learning to solve problems. This includes the opportunity to *receive hints, and to get feedback on wrong answers or approaches*. We offer various versions of *Learn By Doing* exercises. Sometimes the user is taken through the steps of a procedure, and is expected to perform the steps one at a time. In other instances, as in the example shown in Figure II, users are asked to solve a problem entirely on their own (usually after they have practiced the skill in a guided mode). If they need help, then *scaffolding* is offered in the form of an initial step and, as needed, subsequent steps; at any point users can complete the problem on their own and enter the answer.

The problem depicted in Figure II features two trucks, each with a crane, which are shown successively to tip over because the load is too large. In this problem, we have given the user a 2D model to represent this situation. (The module in which this is found deals with equilibrium; later modules deal with the reduction of 3D situations to 2D models using symmetry.) From the given free body diagram, users are to find the reactions on the tires or supports.

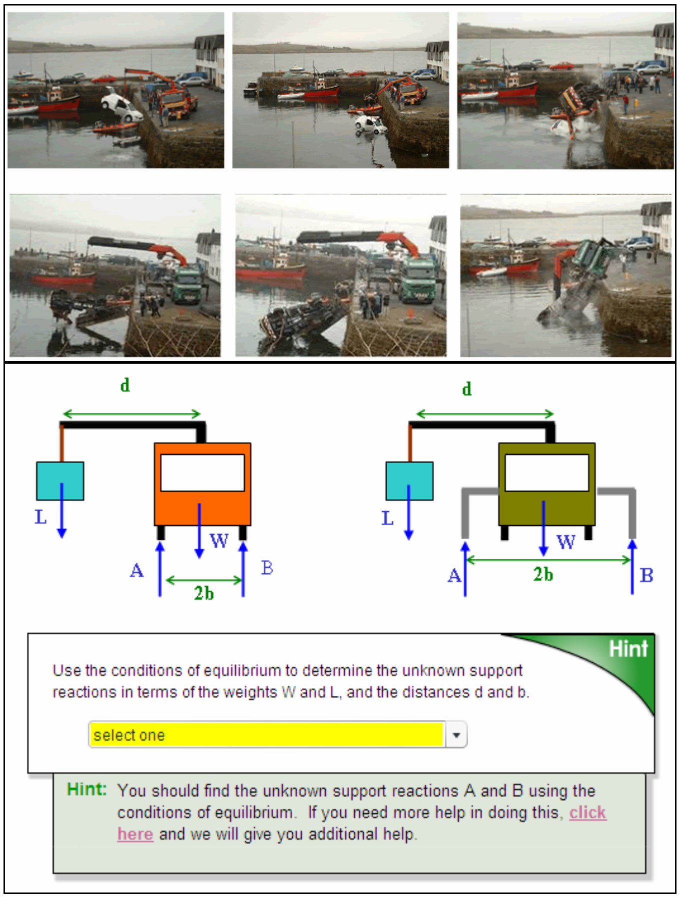

FIGURE II
PROBLEM UTILIZING EQUILIBRIUM UNDER FORCES ACTING IN THE SAME DIRECTION

Figure III pertains to the same problem, now during the scaffolding (the steps refer to four overall steps in solving problems using equilibrium). Notice that students can be prompted to think about strategy (to find one quantity directly, which equation would you use?), and to write down a particular equation of equilibrium, with the algebraic equation to be constructed from multiple pull-down menus.

The problem excerpted in Figures II and III is completed in Figure IV, where we seek to *interpret the solution* that appears in variable form. The chain of reasoning is not conveniently reduced to a series of multiple choices. Thus, with this *Submit and Compare* exercise, students submit an answer and then view the expert answer. Such exercises are fruitfully undertaken by students multiple times (several days or weeks apart) as they try to reproduce the reasoning independently.

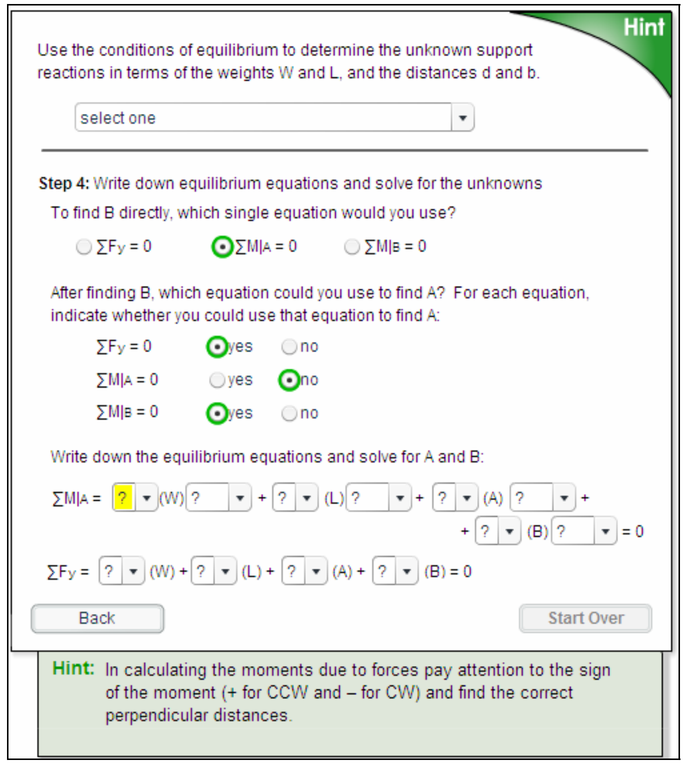

FIGURE III
FOURTH STEP OF SCAFFOLDING OFFERED TO USER WORKING ON PROBLEM SHOWN IN FIGURE II

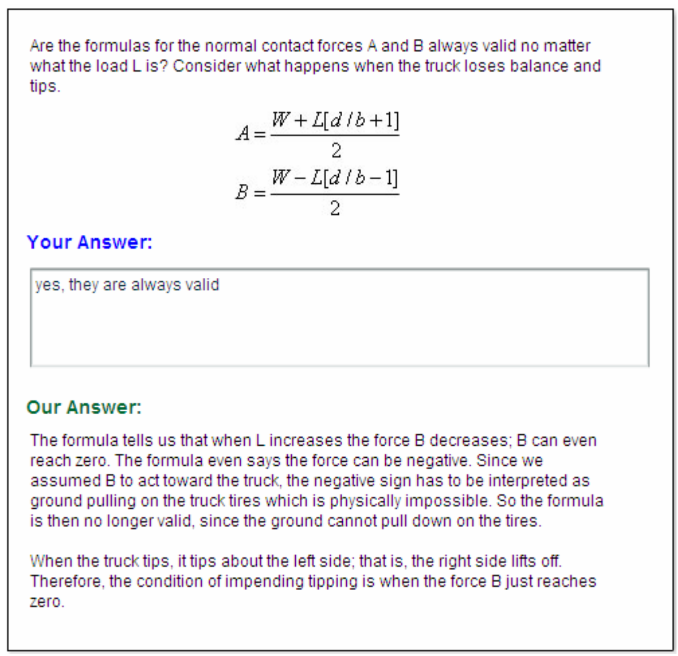

FIGURE IV
SUBMIT AND COMPARE EXERCISE THAT COMPLETES PROBLEM OF FIGURE II, IN WHICH THE USER ATTEMPTS TO EXPLAIN HOW THE FORMULAS THEY FOUND SUGGEST THE CONDITIONS UNDER WHICH TIPPING OCCURS

Guided Simulation

In many subjects, dynamic simulations can help significantly in conveying an idea. Such simulations may be simple, with no user control other than to start and stop, or with the user having control over one or more parameters. The latter enables the user to pose and answer what-if questions.

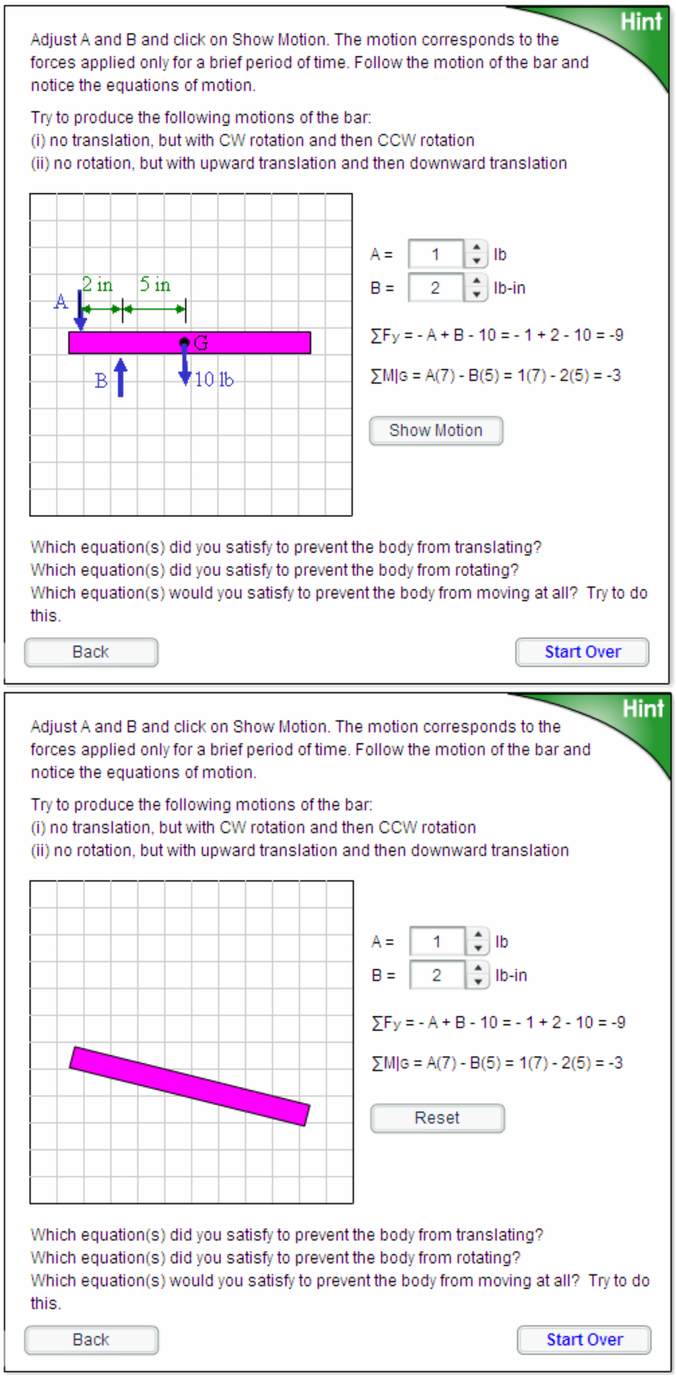

FIGURE V
GUIDED SIMULATION IN WHICH USER DISCOVERS THAT FORCES ON A BODY ONLY MAINTAIN THE BODY IN EQUILIBRIUM IF THE TENDENCIES FOR BOTH TRANSLATION AND ROTATION ARE ZERO

In Figure V we show a simulation in which the user alters the magnitudes of two forces (representing supporting fingers) and observes the resulting motion of the bar. We use this as discovery learning to permit students to recognize that equilibrium (keeping the bar motionless) involves keeping both forces and moments balanced. Users also see the updated equations that capture force and moment summation, which serves to strengthen the relation between the algebraic result and the physical result (motion). Moreover, this exercise is guided, in that users are prompted to produce several different outcomes; of course, users can freely explore as well.

Did I Get This?

At the close of each Learning Objective, student progress is assessed with one or more Did I Get This exercises. One such exercise, pertaining to equilibrium when the lines of action of forces run through a common point, is shown in Figure VI.

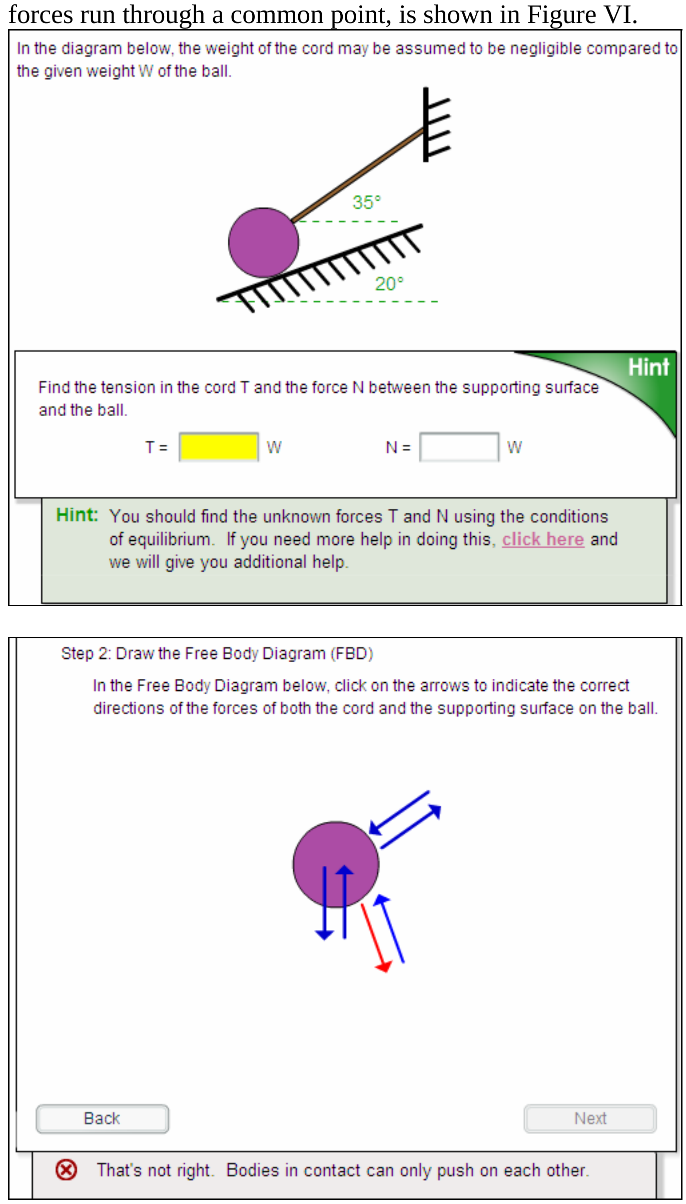

FIGURE VI
FEEDBACK TO WRONG ANSWER SELECTION IN DID I GET THIS ASSESSMENT.

In this exercise, which follows other activities that develop the component skills associated with solving such a problem, the user is expected to solve the problem independently. However, users that get stuck can ask for scaffolding; at any point they can complete the problem on their own and enter the answer. The lower figure shows the second step of the solution process in which the free body diagram is being drawn. The user is choosing the directions of the unknown forces. The incorrect sense for the to-be-determined normal force of the supporting surface on the ball has been chosen. Whenever an interpretation can be placed on the wrong answer choice, feedback to the user explains the principle at issue. Often DIGT problems are dynamically generated, with altered numbers and/or geometry, so multiple opportunities for additional learning and practice are available.

TESTING, ASSESSING AND IMPROVING

Initial versions of three modules were user-tested at CMU in Spring 2006 by experts in human computer interaction (HCI). Students were hired to spend one hour on various portions of modules and then to take a test related to their learning; these students had taken physics, but had not completed, nor were enrolled in, a Statics class. The HCI study revealed several issues of relevance to the future development of the course. Significant issues included potential misunderstandings regarding which displays are interactive and which are not, and, in certain instances, what action, if any, was expected of the user. Five completed modules were used in a blended mode during the first five weeks of two sections of a Statics class at Miami University in Spring 2007. Students worked through some modules in class, so the instructor could observe and offer help if needed. Students were encouraged to submit comments about the online materials.

Instructor observations and comments from students did offer important insights. For example, the benefit in having drawing and calculating tools available online became apparent. Since there are so many interactions and testing of student knowledge on small and large scales, and since many of the small scale assessments only require the student to think without writing, there is a need to signal when the student should expect the need to write. In addition, small portions of the online course where the expected pace of learning was too ambitious were identified and flagged for redesign.

The OLI environment allows for full logging of student work (every type and click). While we have not yet analyzed the logged data, together with the paper and pencil assessment data these will provide an initial basis to probe the effectiveness of various elements of the course across multiple dimensions. Those findings will be reported in the near future.

SUMMARY

The potential of online materials to enhance a traditional lecture-based engineering science course has been explored. The potential enhancements that have been surveyed include: increased levels of active learning, opportunities to leverage voice and graphics, integration of simulation, guidance and feedback during problem solving, more frequent and finer grained assessment, more timely tracking of progress and recognition of potential difficulties, more convenient review, and improved feedback to instructors.

Course materials presented here are part of an online Statics course that is being developed as part of the Open Learning Initiative at Carnegie Mellon University. OLI seeks to create and sustain freely available, cognitively informed learning tools that take advantage of the digital learning environment. Specific examples from these materials are displayed which illustrate the potential of online learning materials.

Initial versions of course modules were subjected to user-testing, which revealed potential problems that users might encounter. Recently, five modules were tested in a blended-mode, integrated into a lecture-based Statics course. Student comments, together with instructor observations, prompted ideas for overall enhancements of the course. More detailed analysis of logging data and in-class paper and pencil assessments, to be reported in the future, should enable more definitive conclusions as to effectiveness of the materials in promoting learning.

ACKNOWLEDGMENT

The authors thank Candace Thille, Marsha Lovett, Bill Jerome, and Aaron Bauer for their thoughtful input throughout the process of developing the OLI Statics course. Support by the William and Flora Hewlett Foundation, by Miami University Department of Mechanical and Manufacturing Engineering, and by the Department of Mechanical Engineering at Carnegie Mellon University, is gratefully acknowledged.

REFERENCES

[1] National Research Council, (1999), How People learn: Brain, Mind, Experience and School, Committee on Developments in the Science of Learning, Bransford, J.D., Brown, A.L., Cocking, R.R. (Eds.), Washington, D.C., National Academy Press.

[2] A.Dollár, P.S.Steif, An Interactive Cognitively-Informed Online Statics Course, 2006 Frontiers in Education, San Diego, California, October 2006

[3] P.S.Steif, A. Dollár, *Reinventing The Teaching Of Statics*, International Journal of Engineering Education, Vol. 21, No. 4, pp 723-729, 2005

[4] A. Dollár, P.S.Steif, *Learning Modules for Statics*, International Journal of Engineering Education Vol. 22, No. 2, pp 381-392, 2006

[5] Dufresne, R.J., Gerace, W.J., Leonard, W.J., Mestre, J.P., and Wenk, L. (1996), Classtalk: A classroom communication system for active learning, Journal of Computing in Higher Education, 7, pp. 3-47.

[6] P. Black and D. William, "Assessment and Classroom Learning, "Assessment in Education, Vol. 5(1), 1998, pp. 7-73.

[7] R., Moreno, R.E, Mayer, Cognitive principles of multimedia learning: the role of modality and contiguity. Journal of Educational Psychology, 91, 358-368, 1999.